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Utilization of Agro-industrial, Food Processing Wastes and Pollutants for Manufacture of Products of Industrial Value: A Review

Swati Ray[1*], Avik Mukherjee[2] and Uma Ghosh[3]

[1]*Department of Food Technology, Haldia Institute of Technology, Haldia-721657, West Bengal. India.*

[2]*Department of Food Engineering and Technology, Central Institute of Technology Kokrajhar-783370, BTAD, Assam. India.*

[3]*Department of Food Technology and Biochemical Engineering, Jadavpur University, Kolkata-700032, West Bengal. India.*

[*]*Email: rayswati279@gmail.com*

ABSTRACT

Rapid industrialization as a consequence of the population explosion has led to the expansion of the agriculture and food processing sector to feed every mouth and to meet rapidly growing market demand. Extensive harvesting and processing of crops and raw agricultural harvests, and production of secondary and tertiary wastes from industrial manufacturing operations associated with agricultural and food products have impacted the environment in adverse ways, which is causing irreparable damages. To minimize the carbon load on earth, several sustainable technologies have been developed, which can save the environment as well as generate some useful and industrially important products. This review work focuses on the current scenario of these wastes, and their harmful effects on nature in general, and on the environment in particular. It also suggests that sustainable techniques can minimize these harmful impacts, and can instead manufacture some valuable products like antibiotics, enzymes, organic acid, organic chemicals, biomass, pigment, flavors, solid fuel, and bioalcohol. Thus, this is a comprehensive and extensive account of the utilization of agricultural and food processing wastes to derive valuable, useful products.

Keywords: Bioalcohol; Circular Economy; Environment; Pollution; Sustainability

1. INTRODUCTION

The revolution in the food and agricultural sector came up with increased demands for agricultural and food products, as a direct consequence of population explosion, rapid urbanization, and income growth. As a result, large amounts of waste are generated at all levels of the agriculture and food processing sectors. The crops are transported to urban and/or semi-urban centers for further processing and a large proportion of liquid and solid wastes are generated during harvesting, production, transportation, manufacturing, and/or consumption of these produce. Wastes are even generated after the utilization of primary and/or secondary wastes. Accumulation of these wastes may harbor pathogenic microorganisms, and support their growth, and these harmful microorganisms that may leach into soil, water, and air.

Most of these are openly dumped in untreated, unutilized conditions or are burned in landfills. Burning releases greenhouse gases like carbon dioxide, carbon monoxide, nitrous oxide, nitrogen dioxide, and carbon particles, along with ozone and nitric acid. These chemicals, when get mixed up in soil and water streams can cause acid deposition that may compromise ecological balance. However, these wastes are rich in various inorganic minerals and organic materials that may improve soil quality if they are utilized as fertilizer. Moreover, some of these wastes are rich in bioactive components having therapeutic and medicinal values. These useful components can be extracted by various methodologies at a much lower capital expenditure.

Many countries have undertaken and promoted innovative technologies for the utilization and recycling of these wastes, identified as potential renewable sources of bioenergy. The main barriers to this are a lack of proper planning, limited public awareness, and insufficient Government policies, the improvement of which are necessary for a cleaner and greener environment[1,2,3].

Previously, several studies have reviewed valorization of wastes to produce industrially important and valuable products specifically. Ray, *et al.*[4] discussed elaborately on different waste materials from which bio-alcohol can be produced. Other than bio-alcohol, wastes were also utilized to produce organic acids[5], antimicrobials[6], biomass[7] or other bioactive components[8] as discussed in earlier studies. This review has explicitly covered almost all possible manufactured goods that can be produced by recycling wastes using sustainable technologies.

2. WASTE GENERATION FROM THE FOOD AND AGRICULTURAL SECTOR

The food and agricultural sector have huge prospects

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of industrialization of waste utilization, including secondary and tertiary wastes, to produce valuable by-products. Although, it may or may not be possible to get rid of hundred percent of the agriculture and food processing wastes even after recycling, their minimization in the environment is a rather logical and achievable goal. The following table lists some of the major food crops with the residues they generate annually (Tables 1 and 2).

Table 1. Agricultural residues for major food crops[9]

Name of the Crop	Crop Residue rate (%)	Crop residues per 1000 tons
Staple crops		
Rice	55	21,298
Maize	250	11,328
Sweet potato	45	595
Cassava	75	7,046
Total		40,269
Industrial Crops		
Sugarcane	65	10,483
Peanuts	20	106
Soybean	10	26
Total		10,616

Livestock rearing creates solid wastes such as manure and other organic materials liquid wastes like urine, and wash water (for bathing of animals) from cages, barn, and/or slaughterhouses. Most of these spontaneously developed farms lack proper treatment facilities for these wastes and thus cause serious pollution problems.

According to the Department of Animal Health (DAH), accumulated manure (25%) is collected and packaged for sale to targeted consumers who will use it as fertilizer or fish feed; 20%, 10%, and 45% are reutilized for biogas production, composting and for discharging into the environment untreated respectively. This waste can generate greenhouse gases and also cause water pollution. Animal manure may contain various microorganisms and parasite eggs, which can survive to potentially harm the health of higher organisms including humans and animals. Additionally, wastes from the farm may include a significant amount of unused residues of food and animal corpses of livestock which are sources of pathogenic microorganisms. The nature of the waste depends upon animal species, feed, gender, hygienic practices, and method of waste treatment[9].

While agriculture mainly deals with raw or unprocessed wastes from plant and animal origin, food industries deal with both raw materials and processed byproducts and design their waste treatment accordingly. The fate of waste products to generate industrially important materials can be illustrated in Figure 1.

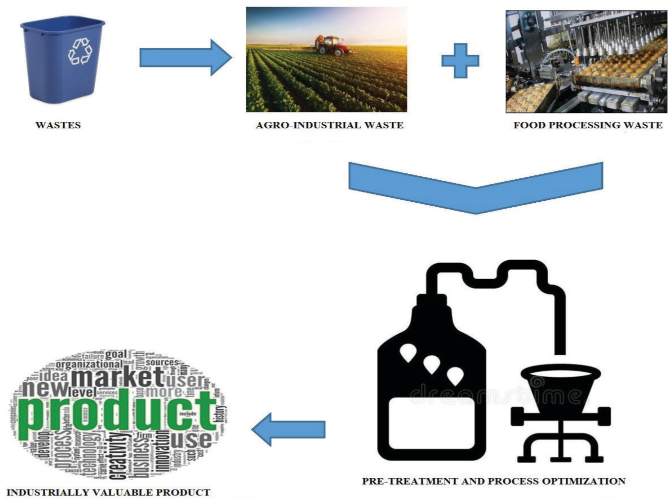

Figure 1. Flow diagram of converting agro and food processing wastes into valuable products

2.1 Food Industry Waste

Annually, about 20% of the total fruit and vegetable production in India is wasted during the postharvest stage, particularly during transportation from production farms to markets. Besides, large quantities of organic wastes and effluents are generated by food processing industries including juice, oil, chips, meat, confectionary, fruit processing units, and many others. There has been a remarkable increase in many food and beverage processing industries to meet the increasing demands for semi-processed and processed foods. In edible oil industries, a large amount of oil cakes, byproducts of oil extraction from the seeds, causes air, water, and soil pollution, as they are rich in greasy and oily suspended and dissolved solids. These food processing wastes have high BOD, COD, and TSS values, which make them nutrient-rich media for microbial processing to produce various high-value products at a reasonable cost. Thus, these industrial residues are pre-enriched with desired nutrients, rendering them as alternative substrates for fermentation, and thus, can be cost-effectively utilized as a source.

2.2 Agricultural Wastes

Agriculture wastes are divided into two types of residues i.e. residues in the field and those after

Table 2. Rate of generation of solid waste from animal breeding[9]

Generation rate (kg/ head/day)	Cow	Buffalo	Pig	Poultry	Goat, sheep	Horse	Deer
Average value	18	15	2	0.2	1.5	4	2.5

processing. Field residues are post-harvest wastes that consist of leaves, stems, stalks, seed pods, and many others, while the processing residues or post-processing wastes are pulp, seeds, husks, straw, shell, leaves, stem, stalk, molasses, bagasse, peel and roots. that can be used for making animal feed, improving soil fertility, manufacturing fertilizer and numerous products. They can improve the irrigation process and can control soil erosion as well. This phytomass consists of cellulose, hemicellulose, and lignin, which are strongly bound by chemical cross-linking and are also termed lignocellulose (LCB) accumulation. They are also rich in starch, and both lignocellulose and starch can be converted to biofuels or biopolymers, as important renewable resources. Two types of extracellular enzyme systems that are used to utilize agricultural residues like sugarcane bagasse, corn cob, wheat and rice bran, wheat straw and others are hydrolytic (polysaccharide degradation) and ligninolytic (lignin degradation that opens phenyl rings) enzymes, used to produce bio-alcohol 2. Fermentation is a cost-effective process of utilizing low-value substrates like agricultural wastes, as great potential alternatives to the traditional method of acid hydrolysis[10].

3. IMPACT OF WASTES ON THE ENVIRONMENT

The earth is equipped with a natural cycle, by which it maintains environmental equilibrium, and systematically recovers from routine environmental degradation. For example, forest soil is rich and fertile due to biomass recycling of leaves and other plant and animal residues that fall on it. This natural enrichment of soil has resulted in massive deforestation, to avail fertile land for enhancing agricultural production. The process of agricultural production, in turn, generates loads of waste, which have been and can be recycled into some forms of usable products or substances. For example, rice straw is one of the agricultural wastes, which is used to make roofs of huts, and to feed livestock since ancient times. The twigs and small branches of trees have been used as fuel for thousands of years. Agricultural wastes are also composted to produce organic fertilizers, which are profusely used by farmers all across the globe, as organic foods are gaining the market. This process has helped many poor farmers to decrease their farming costs giving almost the same output in soil fertility[1,11].

The raw material source decides the composition and quantity of agro-industrial wastes along with the characteristics of the products and manufacturing steps. In general, these wastes have high BOD, COD, and suspended solids causing severe water, soil, and air pollution, if not managed properly or treated before disposal. The food industries that generate waste includes canned, frozen, and dehydrated fruits and vegetables, soup, potato chips, specialty items, baby food, edible oil, dairy, pickle, peanuts, tea, coffee, chocolate, fish and seafood, meat, and poultry processing lines.

3.1 Water Pollution

It is caused by highly biodegradable effluents having soluble organics that are difficult to remove chemically or by pigments in various raw products that cause water discoloration or by putrescible liquid wastes that cannot be stored for long. Effluent from edible oil contains high concentrations of suspended fat, oil, and floating grease that are difficult to remove. They usually have very high BOD_5, suspended solids, dispersed organics, and dissolved solids. Whey from the dairy industry, brine from pickle manufacturing, and wash water from livestock rigged with organic, and inorganic matter, microorganisms, and parasite eggs are some of the common examples.

3.2 Solid Waste Accumulation

Frozen and canned meat or muscle products may form putrescible wastes from peeling and trimming or screening operations. These wastes need to be treated quickly to convert them into by-products such as fertilizers and/or feed. Peanut and cocoa industries accumulate large quantities of shells and hulls whereas tea chests, spent tea and coffee grounds are primary by-products of tea or coffee manufacturing industries. Processing of poultry, crab, shrimp, or fish produces large quantities of shells, entrails, offal, feathers and fins, which are commonly utilized to manufacture animal feed.

3.3 Air Pollution

Odours and smoke from processing operations, wastewater treatment, solid waste disposal, moisture droplets from steam plumes and entrained particulates can cause air pollution, if not properly treated, maintained, utilized (where appropriate), and/or disposed of. Particulate emissions from handling beans, food grains, or pomace may discharge occasional toxins or specific allergens. The roasting odor from tea, coffee, or chocolate industries and odors emanating from cages or burns, as a result of an accumulation of animal wastes, putrefaction of organic wastes in manure, urine, and/or from unused, excess feed are some of the routine causes of air pollution from agriculture, and agro-based industries[9,11]

4. MANUFACTURE OF INDUSTRIALLY IMPORTANT PRODUCTS FROM WASTES

The valuables that can be generated by processing these wastes may have therapeutic or medicinal values; may be utilized in various chemical or pharmaceutical industries; may be used to make some regional cuisines or simply utilized to produce solid, liquid, or gaseous biofuels (Table 3).

Table 3. Production of different industrially important products from agriculture and food wastes

Name of the waste	Nature of fermentation with microorganisms	Product generated	Ref.
Antimicrobial/ Anticancer/ Antioxidant			
Pineapple waste	Solid State Fermentation using Kluyveromyces marxianus NRRL Y-8281	Anticancer and antioxidant properties of the methanol-extracted waste	12
Apple and Avocado peel and pomace	Extraction	Catechins, epicatechin, hydroxycinnamates, anthocyanins, glycosides, quercetin, chlorogenic acid, gallic acid, phloretin glycosides, procyanidins, cyanidin 3-glucoside, homogentisic acid	13
Banana peel	Extraction	Anthocyanins, cyanidin gallocatechin, delphindin, catecholamine	13
Antibiotics			
Corn cob and pomace, sawdust, rice hulls, Groundnut shell, cassava peels, and household kitchen waste.	Solid State Fermentation using Streptomyces rimosus TM-55, Streptomyces rimosus	Antibiotic oxytetracycline	14,15,16
Oil cakes from coconut, groundnut, the shell of ground nut, and rice husk.	Solid State fermentation using Amycolatopsis Mediterranean MTCC 14	Rifamycin B	17
wheat bran, cotton seed meal, apple pomace, and soybean powder	Solid State fermentation using Streptomyces fradiae NCIM 2418	Neomycin	18
Regional delicacies			
Peanut press-cake	--	Fermented product Oncom Kacang.	19, 20
Solid wastes of Tahoo (soybean Curd)	--	Fermented product Oncom Tahoo.	19, 20
Solid mungbean waste (Phaseolus radiata) and starch flour (Hunkwe)	--	Fermented product Oncom Ampas Hunkwe.	21
Soybean milk wastes	--	Protein-rich human food like Tempeh or similar kinds.	22
Enzymes			
Agri wastes	Solid state fermentation by thermophilic fungus strain, i.e., Thermoascus aurantiacus.	Endoglucanase and β- glucosidase	23
Corn cob	Solid-state fermentation coupled with enzymatic treatment using Sporotrichum thermophile	Cinnamoyl esterase and xylanase	24
Bran of wheat, green gram, black gram, maize, rice, flour of corn, barley, jowar, and wheat rawa.	Solid-state fermentation using Aspergillus sp.	Amylase and Glucoamylase	25, 26
Wheat bran	Solid-state fermentation using Aspergillus awamori nakazawa MTCC 6652	Amylase and Protease	27
Agricultural waste, Papaya Waste, Orange peel, Coconut oil cake, Bran of wheat, rice, black gram, and soybean.	Solid-state fermentation using Aspergillus niger MTCC 104, Aspergillus niger, Aspergillus oryzae	α-amylase	28, 29, 30, 31, 32
Rice bran and Corn bran	Solid-state fermentation using Bacillus sp PS7	Thermostable α-Amylase	33

Name of the waste	Nature of fermentation with microorganisms	Product generated	Ref.
Stalks of candelilla, sugarcane bagasse, husks of coconuts, and corn cobs	Solid-state fermentation using *Aspergillus niger* GH1	Ellagitannase	34
Oil cakes from palm kernel, groundnut, and linseed	Solid-state fermentation using Aspergillus ibericus. MUM 03.49, Penicillium aeruginosa and Candida rugosa.	Lipase	35, 36, 37
Wheat bran and orange peel	Solid-state fermentation using Penicillium notatum NCIM 923.	Pectin methyl esterase	38
Fruits peel waste	Solid-state fermentation using Aspergillus niger	Invertase	39
Organic acids			
The outer cover of gallo seeds	Fermentation using Rhizopus oryzae	Gallic acid	40
Tea wastes with sugarcane molasses	Fermentation using Aspergillus niger	Gluconic acid	40
Wheat kernels	Fermentation using Aspergillus oryzae	Oxalic acid	40
Carrot-processing waste, Sweet sorghum, Sugarcane bagasse, and Cassava bagasse	Fermentation using Rhizopus oryzae, Lactobacillus paracasei and Lactobacillus delbrueckii	Lactic acid	40
Pineapple wastes	Fermentation using Aspergillus foetidus	Citric acid	40
Organic chemicals			
Corn cob	Solid-state fermentation coupled with enzymatic treatment using Sporotrichum thermophile	Phenolics	24
Orange peel waste	Stirred tank reactor using Bacillus subtilis OK 2	Poly-3 hydroxybutyrate	41
Oils of castor, coconut, corn, rapeseed, olive, sunflower, and barley bran, cassava flour and potato waste, peanut cake, rice, and wheat bran.	Pseudomonas aeruginosa PB3A.	Biosurfactant	42
Waste like potato peel	Submerged Fermentation using Xanthomonas campestries MTCC 2286, Xanthomonas citri, Xanthomonas oryzae, and Xanthomonas musacearum.	Xanthan	43
Immobilized matrix			
Ten agro wastes which include Peels of lemon and orange, apple pomace, creosote bush leaves, Caribbean agave, shell of pistachio and pecan nut, wheat bran, coconut husk, and bean residues.	Solid-state fermentation in immobilized form	Immobilized carrier	44
Salacca wallichiana stem	Immobilization carrier for lipase production	Immobilized matrix	45

Name of the waste	Nature of fermentation with microorganisms	Product generated	Ref.
Chicken eggshell membrane powder	Immobilized enzyme carrier of β galactosidase	Immobilization matrix of enzymes	46
Biomass			
16 diverse agro-industrial wastes(Rice straw, Cotton waste, Khaya ivorensis, Terminalia ivorensis, Androgon sp, Groundnut shell, Melon pericarp,Cassava peels, Banana leaves, Palm wastes, Con cob, Cocoa leaves, Coffee leaves, Paper wastes, Soybean wastes and Poultry manure)	Submerged condition of fermentation	Oyster mushroom species Pleurotus tuber-regium	47
Banana stalks, Bahia grass, Rice, and wheat straw.	Solid bed of agro waste	Oyster mushroom pink and gray species and the species Pleurotus sajor-caju	48, 49
Coffee husks	Solid bed of coffee husks	Oyster mushroom	50
Straws of Paddy and Varagu, Sorghum stem, and Sugarcane trash	Solid bed of agro waste	Oyster Mushroom species Pleurotus eous and Pleurotus platypus.	51
Cucumber and orange peels	Submerged fermentation using Sachharomyces cerevisiae	Single-cell protein (SCP)	52
Pigments			
Molasses supplemented with sucrose, zinc sulfate, and magnesium sulfate, extract of corn and yeast	Fermentation using Penicillium oxalicum	Arpink Red	53
Corn fiber and ethanol processing by-products	Fermentation using genetically modified fungus Fusarium sporotrichioides	Lycopene	53
Orange processing waste	Solid state, Semi-solid state and Submerged fermentation using *Monascus purpureus* ATCC 16365 and *Penicillium purpurogenum* CBS 113139.	Orange pigment	54
Flavors			
Maize, rice, wheat, and sugar beet pulp by-products	Extraction using organic solvents	Ferulic acid (Precursor of Vanillin production)	40
Olive mill waste	Microbial fermentation using Rhizopus oryzae and Candida tropicalis	d-limonene	55
Soya bean, apple pomace, cassava bagasse and amaranth	Solid state fermentation using Ceratocystis fimbriata	Fruits aroma (mixture of Alcohol, aldehyde, ketones, and esters)	56
Gas production			
Corn straw	Pre-treatment and anaerobic digestion	Biogas	57
Agriculture residues rice straw, empty fruit bunches, cassava pulp, decanter cake, pineapple peel, and along with weeds, i.e., Typha angustifolia L. and Eichornia crassipes	Pre-digested Solid state fermentation using natural microflora	Biogas methane	58

Name of the waste	Nature of fermentation with microorganisms	Product generated	Ref.
The straw of soybean, black gram, red gram, wheat stalk, and ground nut shells	Digestion using concentrated sulphuric acid and catalysts.	Biogas	59
Solid fuel			
Grape Marc from the winery	hydrothermal carbonization to make hydrochar	Solid biofuel	60
Palm oil fronds and trunks	hydrothermal treatment	Solid fuel	61
The mixture of rice husk, cornstarch, glycerol, and acetic acid.	Homogenization and oven drying	Solid fuel	62
Bioalcohol			
Water extract of Bagasse, spent tea liquor, and potato wash water	Submerged Fermentation using Saccharomyces cerevisiae MTCC 180	Bioalcohol	63
Vegetable wastes like peels of potato, carrot, and onion.	Solid state fermentation using Saccharomyces cerevisiae with saccharification process by Penicillium sp.	Bioethanol	64
Agro-industrial waste and starch industry wastewater.	Fermentation using Clostridium beijerinckii	Biobutanol	65
Straw, sawdust, and corncobs	Solid-state fermentation using Saccharomyces cerevisiae NCYC 3451	Bioethanol	66
Waste animal fat	High-temperature treatment using methanol along with catalysts nickel and magnesium.	Biodiesel	67
Waste fish oils and used cooking oils	Direct utilization or mild heat treatment	Biofuel	68

5. MARKET VALUE AND BIO-ECONOMY

An estimated 181.5 billion tonnes of lignocellulosic biomass is manufactured globally in a year, of which 8.2 billion tonnes are utilized at present, and the rest remain untreated and degrade as waste. Approximately 7 billion tonnes are by-products of agriculture, forest, and grassland activities, of which only 17% are residues of agricultural production. So, efficient utilization of these wastes is becoming a necessity to expand the prospects of developing a bio-economy[69]. This agro-industrial waste biomass is widely available and forms the substrate for biofuel production by fermentation. Optimized technologies, life cycle analysis, and economic assessment of these processes can contribute to the development of these nature-friendly concepts. Various types of pretreatment methodologies, valorization techniques, integrated approaches, and optimization can increase the recycling value of these substances. The processes are not only a step towards the sustainable circular bio-economy but also an art of living life in a zero-waste world[70].

6. CONCLUSION

The world is generating excessive amounts of waste, as much as 0.74 kg per head daily. These wastes are rich in nutritional components that also have a very high biological oxygen demand, and may cause environment pollution if dumped untreated or burned. These wastes are useful substrates for industrial-scale microbial fermentation to generate simpler molecules of industrial value. As raw materials they drastically reduces cost of manufacturing and contributes towards the maintenance of ecological balance. Currently, about 10% of the total energy demands in the world is met with the help of biomass generation which can definitely be increased along with making novel materials such as biodegradable food packaging systems through up-cycling and proper handling of these wastes. With effective national and international policies, local initiatives, and mass awareness, through joint ventures of scientific methodologies, innovation, and economic management, utilization of these wastes can immensely boost investment towards sustainable development.

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CONTRIBUTORS

Ms Swati Ray obtained her master's (M-tech) from Jadavpur University, Kolkata, West Bengal and pursuing her PhD. from there as well. She is currently working as an Assistant Professor for the last 15 years at the Department of Food Technology in Haldia Institute of Technology, Haldia, West Bengal. Her current research interest includes utilization of food waste and isolation of useful bioactive components.
She was involved in conception, manuscript design, experimentation, data collection, literature analysis and manuscript writing.

Dr Avik Mukherjee obtained his MS and PhD. from University of Minnesota, Minnesota. He is currently working as an Associate Professor and head of the Dean of Research and Development in the Department of Food Engineering and Technology, Central Institute of Technology Kokrajhar. His current research focuses on the use of biopolymer-based food packaging and its value addition using nano-composite synthesized from wastes.
He was involved in the conceptualization, final proofing, manuscript editing, and framing of the study.

Dr Uma Ghosh obtained her master's (M-tech) and PhD. from Jadavpur University, Kolkata, West Bengal. She is an Emeritus Professor in the Department of Food Technology and Biochemical Engineering, at Jadavpur University, Kolkata. She has recently retired from her Department from her previous position and is currently working as an advisor for the Department.

She was involved in conceptualization, final proofreading,